# THE FULMINATING FIRE EXTINGUISHER (A)

This case history relates the chain of events leading to the "explosion" of a stainless steel fire extinguisher which severely injured the individual handling it at the time. Investigation into the cause of the accident was necessary since the injured party entered suit. Before settlement was reached, five defendants were involved.

Appreciation is expressed to Mr. A. R. Bowles III, of Bowles and Boyd, Richmond, Virginia, for extending the courtesy of his files to use in writing this case history in failure analysis.


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## The Circumstances

Mr. W., an employee of a security organization employed by a manufacturer located in south central Virginia, was cleaning a jeep fitted out as a patrol vehicle and small fire truck. He was in the process of lifting out a fire extinguisher and putting it on the ground when it "exploded". The barrel (or shell) "took off" and landed about 50 m (160 ft) away. Mr. W. was struck on the right side of his face and head, receiving extensive injuries. He also suffered lacerations on the fingers of his right hand.

Mr. W. entered suit against the manufacturer of the fire extinguisher and the outfitter of the jeep. The private label of the outfitter was on the fire extinguisher although this had been attached by the actual manufacturer and the extinguisher had never been removed from the shipping carton by the outfitter. A claim of $250,000 was entered against each of the two defendants. At a later time, the security organization, the plant which employed the security organization, and the Underwriter's Laboratory were added as defendants.

## Observations

The fire extinguisher was about six years old. During that entire period it had been in the patrol jeep except for brief periods when the jeep was being cleaned. There was no evidence that this specific extinguisher had been inspected since it was purchased, although it was normal practice to have regular inspection of all extinguishers on the premises.

The fire extinguisher was a dry chemical powder type made of stainless steel containing 9.1 kg (20 lb.) of powder. The powder is 92% sodium bicarbonate with the balance being tricalcium phosphate, zinc stearate, and coloring matter. A trigger in the handle normally discharges the contents of a carbon dioxide cartridge with the powder then being blown out through a hose and nozzle.

The safety pin was found at the scene of the accident, not where the barrel came to rest. Since the chain holding the pin was forcibly detached and Mr. W.'s fingers were lacerated, he must have been holding the safety pin in some manner. The dish-shaped bottom of the extinguisher and the powder contents were also found at the scene of the accident. The wire seal through the safety pin was not found after an intensive search.

The $CO_2$ cartridge is sealed with a copper disc. Examination showed that the disc was punctured with a downward angle thus indicating the cartridge had been discharged in a normal manner and had not been exploded from within. There was no evidence of blockage of the hose or powder discharge nozzle.

Figure 1 shows a section of the bottom end of the failed extinguisher. A longitudinal and a circumferential weld are obvious. It was reported that the extinguisher was fabricated from stainless steel. The barrel of the extinguisher was, no doubt, fabricated by forming a flat rectangular sheet into a cylinder with joining accomplished by welding. The end was closed by welding in a "dish" which was formed by pressing or drawing a flat sheet disc into the desired form. The failure surface is equally obvious. There is also an obvious difference in the appearance of the inner surface of the barrel between the portion which contained the dry chemical and the "skirt" which provided a stable base for the extinguisher. The "skirt" portion is obviously covered with a "flaky", "puffy" material while the inner portion of the barrel is quite clean and shiny.

Figure 2 shows the inside surface of the entire "dished" end, which is relatively clean and shiny. Several cracks and ruptures, as well as the fractured edge, are clearly visible.

Figure 3 shows the outside surface of the "dished" end, which obviously is not clean and shiny. This surface is rather thoroughly covered by a deposit which is brownish in color and appears to be the same as the deposit on the "skirt" which is obvious in Fig. 1.

Figure 4 shows a "head-on" view of the crack shown at the right of Fig. 2. Figure 5 shows a "head-on" view of the cracks shown at the left of Fig. 2.

Figure 6 shows a typical region of the failure edge of the "dished" end. The darker regions of this fracture surface were colored with variations and mixtures of reddish-brown and bluish-grey.

QUESTIONS:

1. What, in your opinion, caused the reported "explosion" of the fire extinguisher which led to the accident and injury of the plant guard handling the extinguisher?

2. On the basis of the evidence available to you, which defendant, in your opinion, should be liable for the injuries? If more than one, how would you divide the responsibility?

3. If you do not believe that you have enough evidence, what is your hypothesis as to the cause of the failure? What additional investigations would you perform to conclusively determine the cause of failure? Outline these in some detail.

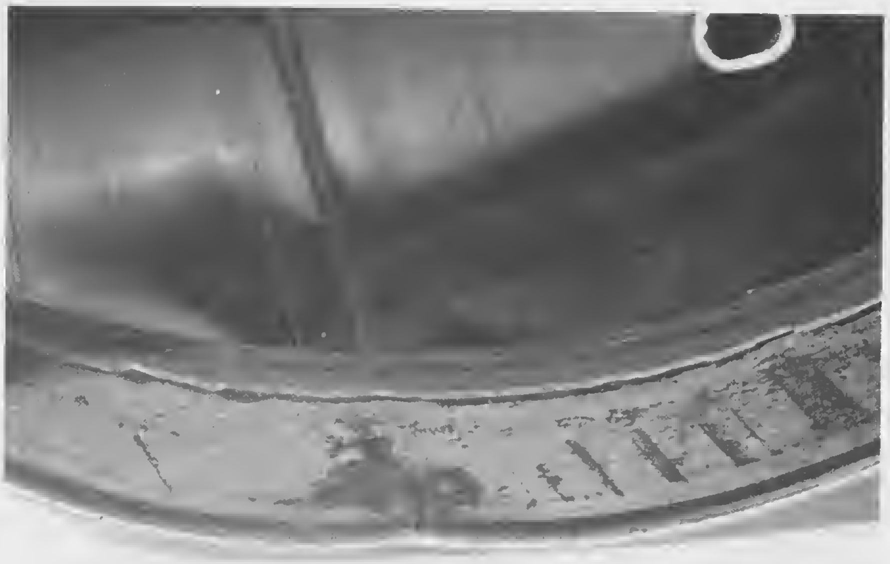

Fig. 1

Section of bottom end of fire extinguisher. The longitudinal and circumferential weld beads are obvious. The fracture edge can be seen. The difference in appearance between the clean interior and the "coated" skirt is obvious.

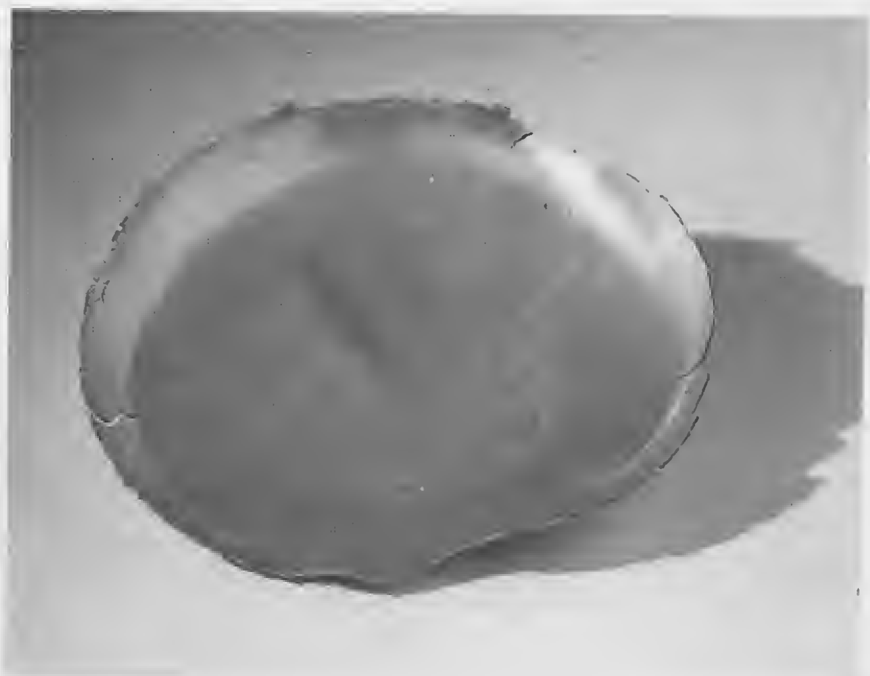

Fig. 2

Inside surface of "dished" end of fire extinguisher. Several cracks are obvious.

Fig. 3

Outside surface of "dished" end of fire extinguisher. There are obvious deposits of material which are not seen on the inside surface. Some cracks are obvious.

Fig. 4

"Head-on" view of cracks as seen on the inside surface of the "dished" end (right side of Fig. 2).

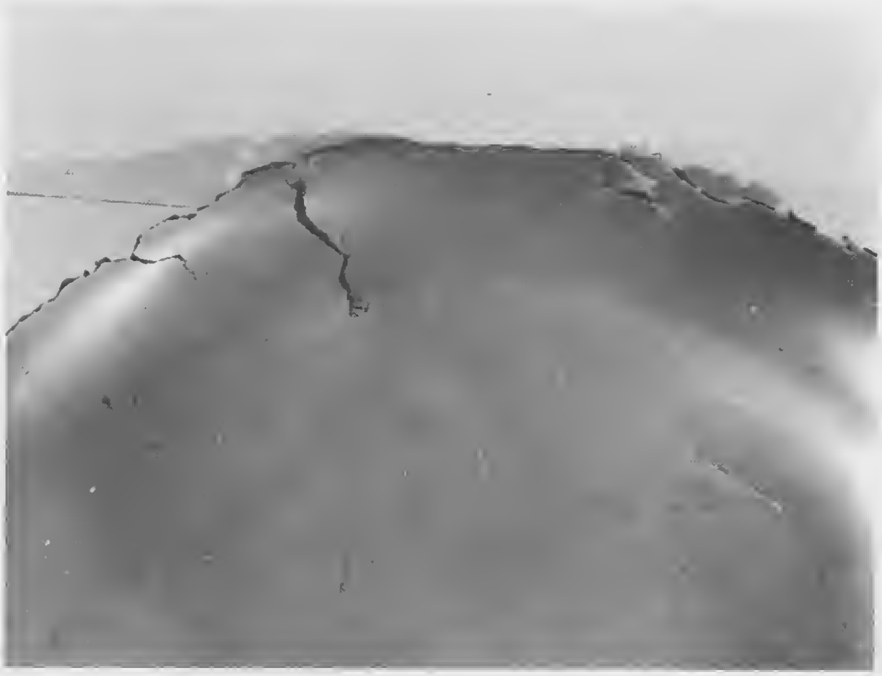

Fig. 5

"Head-on" view of cracks as seen on the inside surface of the "dished" end (left side of Fig. 2).

Fig. 6

Typical portion of failure edge of "dished" end. Contrast between light and dark areas is obvious.

# THE FULMINATING FIRE EXTINGUISHER (B)

## Further Observations

In examining Figs. 4 and 5, it is obvious that the cracks are not straight, but "zig-zag", indicating that the cracks follow along boundaries between individual grains rather than passing through the grains. Thus the cracks are intergranular, not transgranular.

The appearance of Fig. 6 with reddish-brown and bluish-grey regions in contrast with some bright and shiny areas indicates that there was partial failure of the metal prior to the accident. In other words, the colored regions had failed earlier so that only part of the metal (that appearing light in color) was still intact to support the discharge pressure.

It was hypothesized that the basic cause of failure was intergranular corrosion.

## Laboratory Examination

Spectrographic analysis indicated that the material in the "dished" end was either Type 302 or Type 304 stainless steel. Wet chemical analysis was not performed since the hypothesis applies equally well to either type. Spectrographic analysis of the deposit on the outside of the "dished" end indicated the presence of calcium.

Fig. 7 shows the same portion of the "dished" end as Fig. 5 but with an indication of where sections were taken for metallographic examination and the direction of viewing the specimens taken.

Fig. 8 is a photomicrograph of a radial section of the "dished" end in the approximate location shown in Fig. 7. This figure clearly shows the intergranular nature of the fracture (left side of photograph) and penetration into much of the nearby material. Figure 9 is the same section as Fig. 8 after etching. A partial network along the grain boundaries is obvious. Figure 10 is a tangential section of the "dished" end in the approximate location shown in Fig. 7. The grain boundary network is also obvious in this photograph, indicating the network was rather widespread.

## Analysis of Failure

The appearance of both the longitudinal and circumferential welds as well as the distance of the actual fracture from the welds, more than 1.25 cm (1/2 in), indicates that the welds did not contribute to the failure.

It is almost certain that the network around the grain boundaries was present in the stainless steel sheet when the extinguisher was fabricated, as there is no way in which it could develop during the fabrication. This network is probably a chromium carbide (or a complex chromium-iron carbide). This could have been removed before fabricating the extinguisher by heating to about 2000°F and quenching the sheet in water. This carbide network is highly significant since the grains in the immediate vicinity of the grain boundaries are locally depleted in chromium thereby becoming highly susceptible to various corrosive agents, especially chlorine. Chromium in stainless steel provides corrosion protection only when in solution but not when combined with other chemical elements such as carbon.

The forming of the disc into the "dished" end introduces some residual stresses which increase the susceptibility of the stainless steel to corrosive agents. These residual stresses are not necessary for susceptibility in this case. Thus the effect of the initial carbide network along the grain boundaries plus the effect of the cold forming operation rendered the stainless steel highly susceptible to corrosion, especially by chlorine.

There was no conclusive evidence of chlorine as spectrographic analysis will not detect chlorine. The presence of calcium in the deposit on the "dished" end was strongly suggestive. The jeep which carried this fire extinguisher was used for perimeter patrol plus various miscellaneous duties by the plant guard force. It was highly likely that one such duty would be to transport calcium chloride to be spread on icy steps and sidewalks in winter weather. The extinguisher sat in a "well" in the jeep. It is very probable that moisture could collect in this well, at least periodically. A combination of calcium chloride with moisture in a relatively confined space would almost certainly lead to corrosion of a susceptible Type 302 or Type 304 stainless steel[1]. (The use of $CaCl_2$ was later confirmed during deposition of a witness.)

The presence of the carbide network and the residual stresses would probably not have led to failure if the extinguisher had been kept in an environment normally found in office spaces or most laboratories and manufacturing plants. Further, the presumed moist calcium carbide environment would probably not have led to failure if there were no carbide network. The combination was almost certain to result in a classical case of intergranular corrosion which reduced the effective wall thickness of the extinguisher (the "dished"end) to the extent that a sudden and complete failure could result upon discharge of the extinguisher.

## Outcome of the Lawsuit

The case was settled out of court for a total payment to the plaintiff of $34,000. Of this the manufacturer of the extinguisher paid $22,500, the outfitter paid $4,000, the plant owner paid $3,000, and Underwriter's Laboratory paid $4,500.

## Possible Action by Manufacturer

Failure in this fire extinguisher was due to a rather unusual set of circumstances. At the same time, one could argue that this was foreseeable. If you were the manufacturer, what would you now do? Would you avoid the potential problem by heat treating to remove the grain boundary network, by using extra low carbon stainless steel (e.g., Type 304L), or by using a stainless steel having an alloy addition with which carbon forms a more stable carbide than it does with chromium, e.g., Type 347?

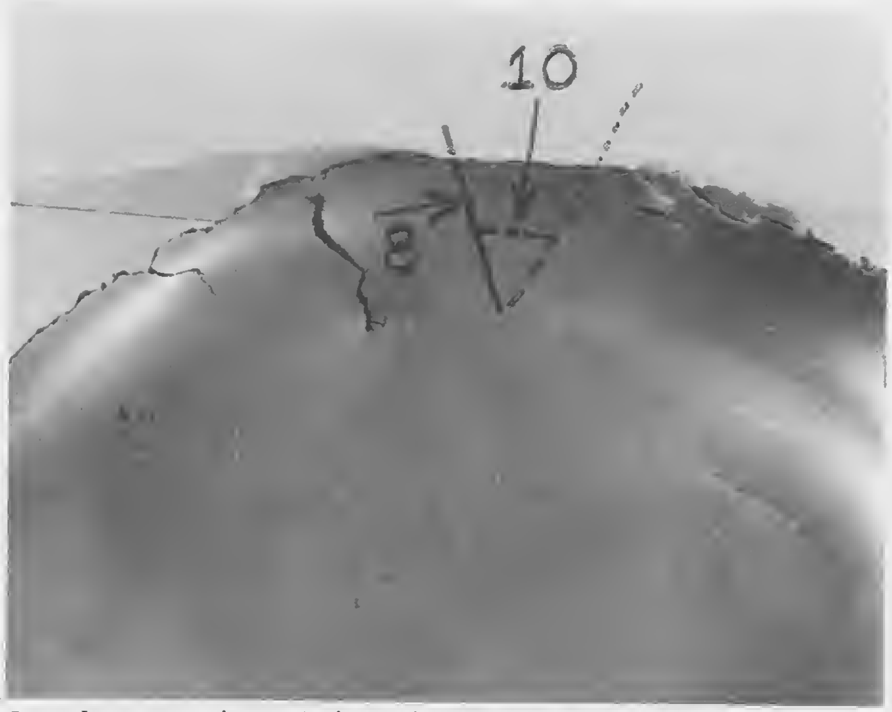


Fig. 7

Cracks as viewed in Fig. 5. Locations of photomicrographs and directions of viewing are indicated.

Fig. 8

Radial section of "dished" end at failure surface. Failure is obviously along grain boundaries. Penetration of corrosion into material near failure surface is apparent.

Polished, unetched Magnification 80X

Fig. 9

Radial section of "dished" end of failure surface. A partial network around the grains, i.e., along the grain boundaries, is apparent

Electrolytic etch in oxalic acid Magnification 80X

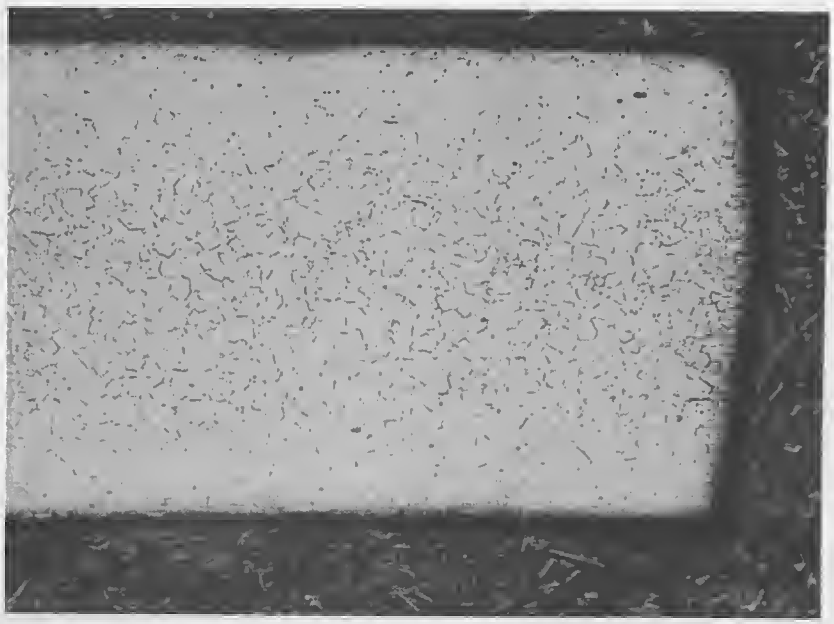

Fig. 10

Circumferential section at some distance inward radially from the failure edge. The presence of the grain boundary network is evidence of a widespread network.

Electrolytic etch in oxalic adic Magnification 80X